Energy Solutions to Air Pollution and Climate Change in California

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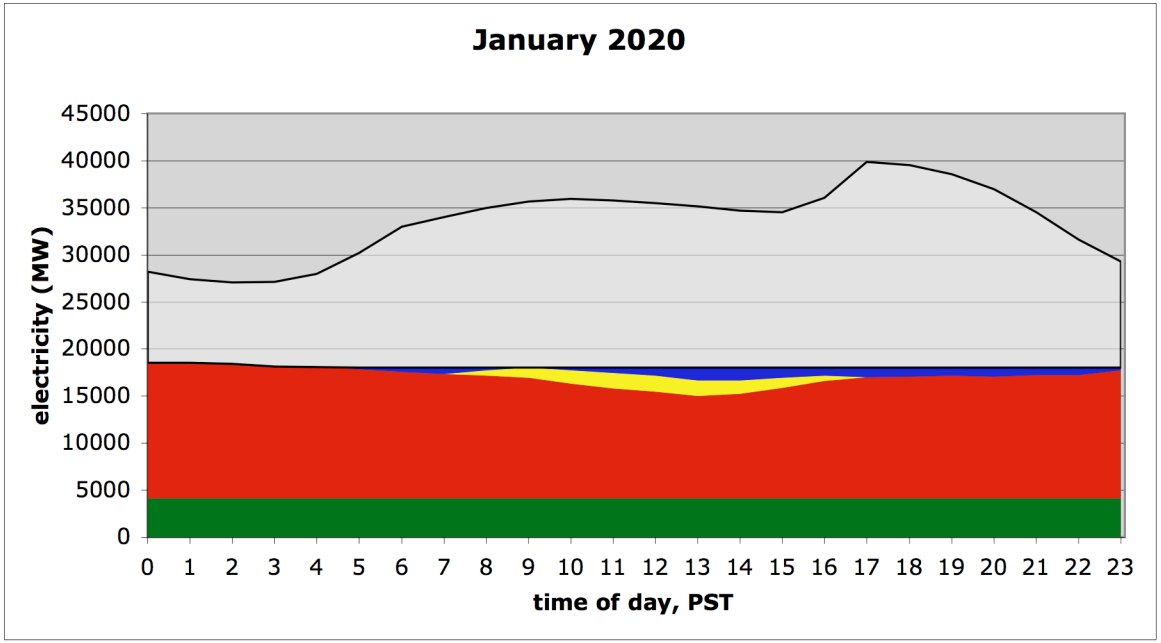
California Renewables for Baseload (MW)

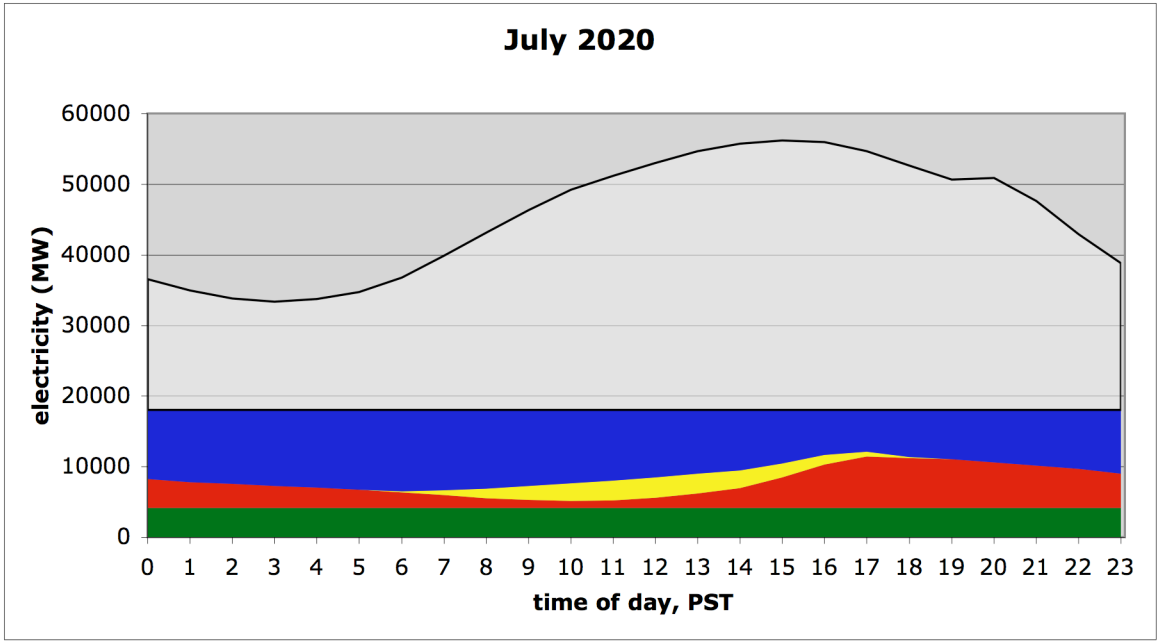
Geothermal installed	1900	
Scenario 1 & 2 (2020)		4500
Wind installed	2400	
Scenario 1		20,000
Scenario 2		37,000
Solar installed	354	
Scenario 1		3,000
Scenario 2		10,000
Hydroelectric installed	13,500	
Scenario 1		6,400
Scenario 2		8,500

Scenario 1: 49.8% of 2020 demand from G+W+S+H

Scenario 2: 73.6% of 2020 demand from G+W+S+H

Electricity Demand (Solid Line) and Conservative Baseload Renewable Supply

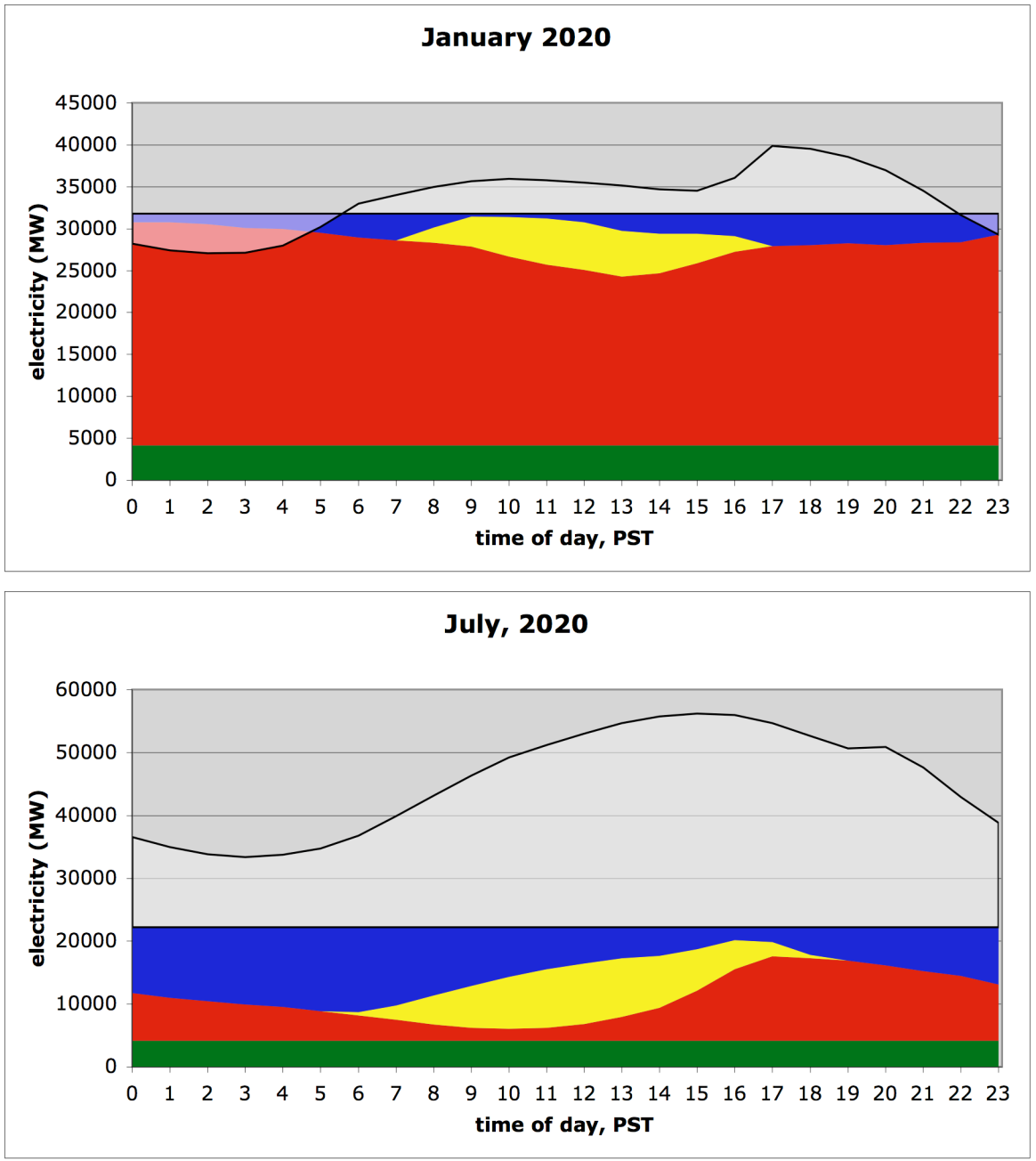




Hydro
Solar
Wind
Geotherm.
Other

Hoste et al. (2007)

Electricity Demand (Solid Line) and Aggressive Baseload Renewable Supply



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Hoste et al. (2007)

California Renewables for Load Matching

Assume 2 million electric vehicles by 2020

Tesla Roadster - 10.29 kW x 4 hr per charge

Full charge 321.8 km (200 mi)

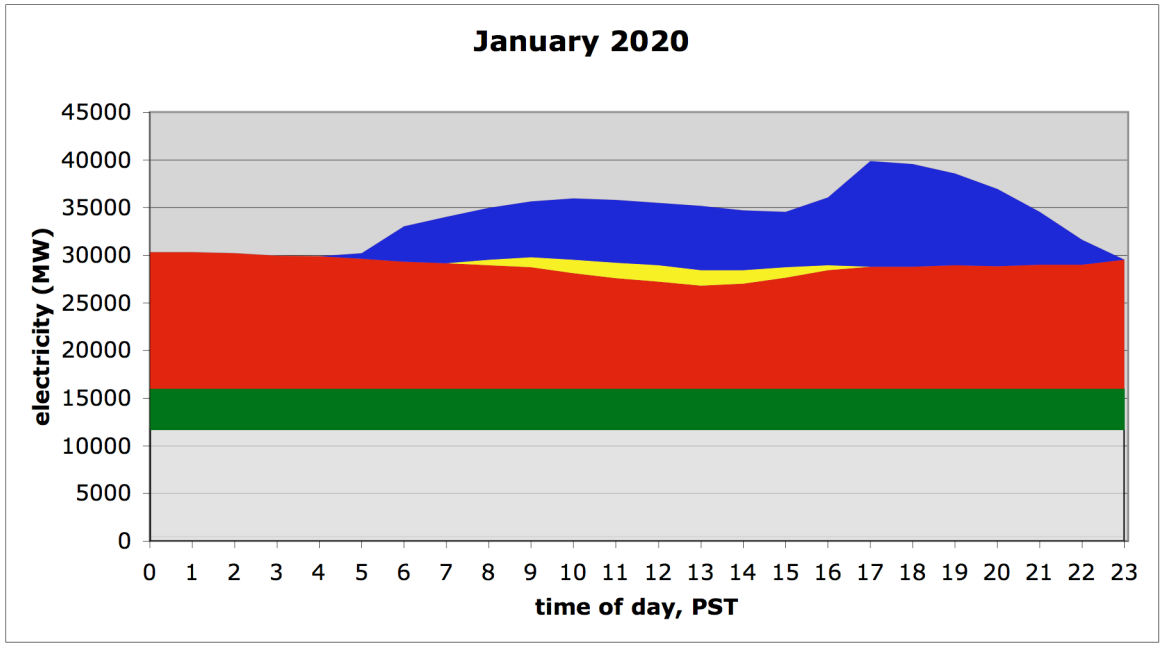
Average driving distance per day 55.1 km (34.2 mi)

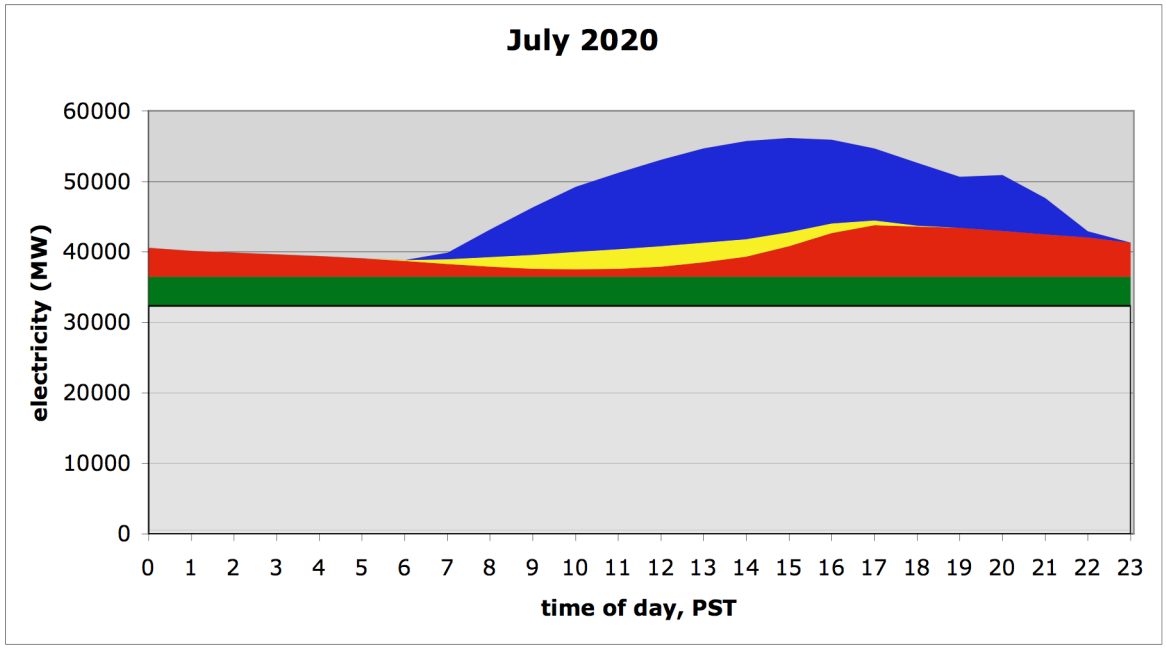
Energy required for charging 12,123 MWh/day

When supply from renewables+baseload exceeds demand, charge vehicles to increase demand

When demand exceeds supply, increase hydroelectric

Electricity Demand and Conservative Load-Matching Renewable Supply





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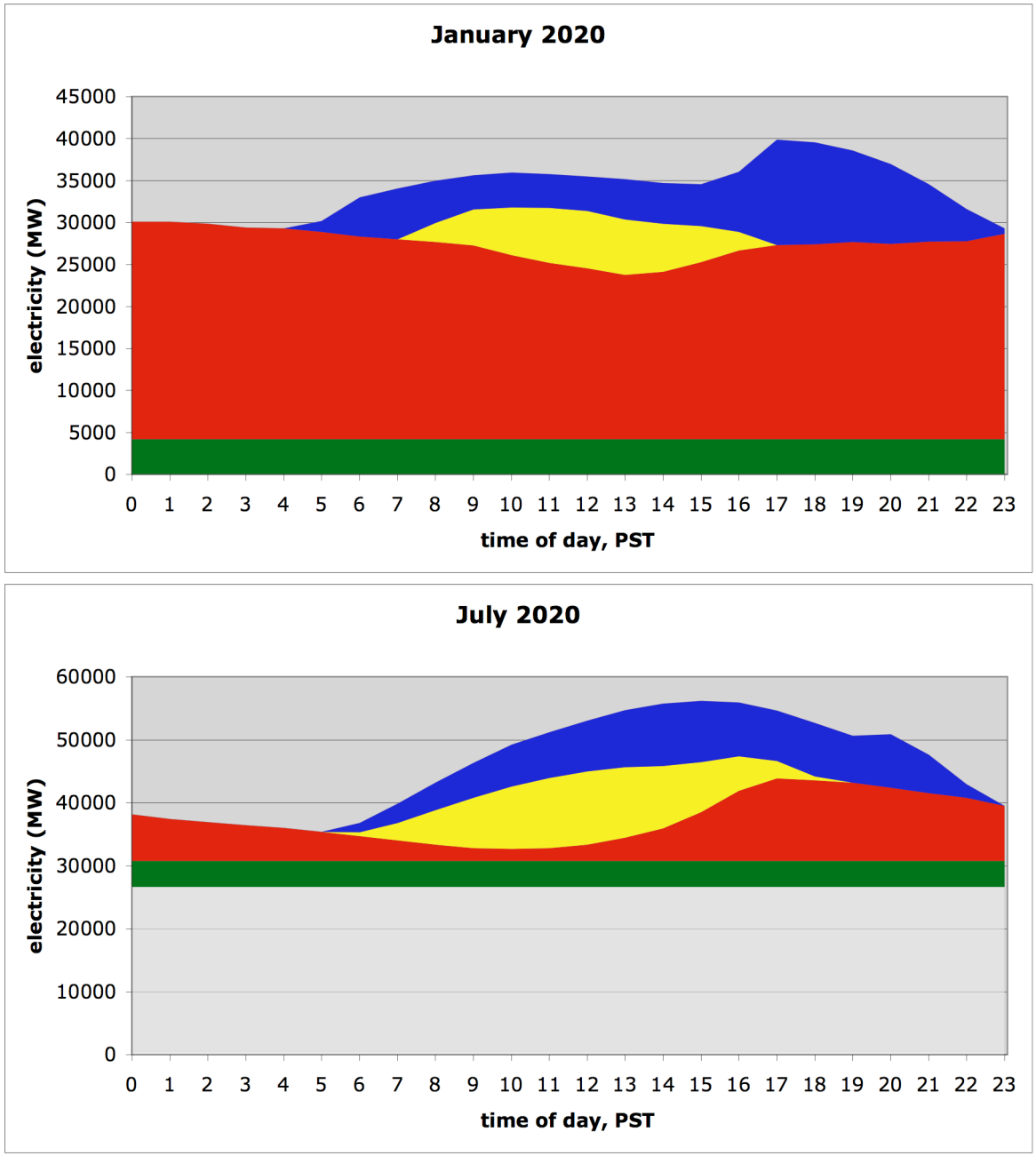
Hoste et al. (2007)

Electricity Demand and Aggressive Load-Matching Renewable Supply



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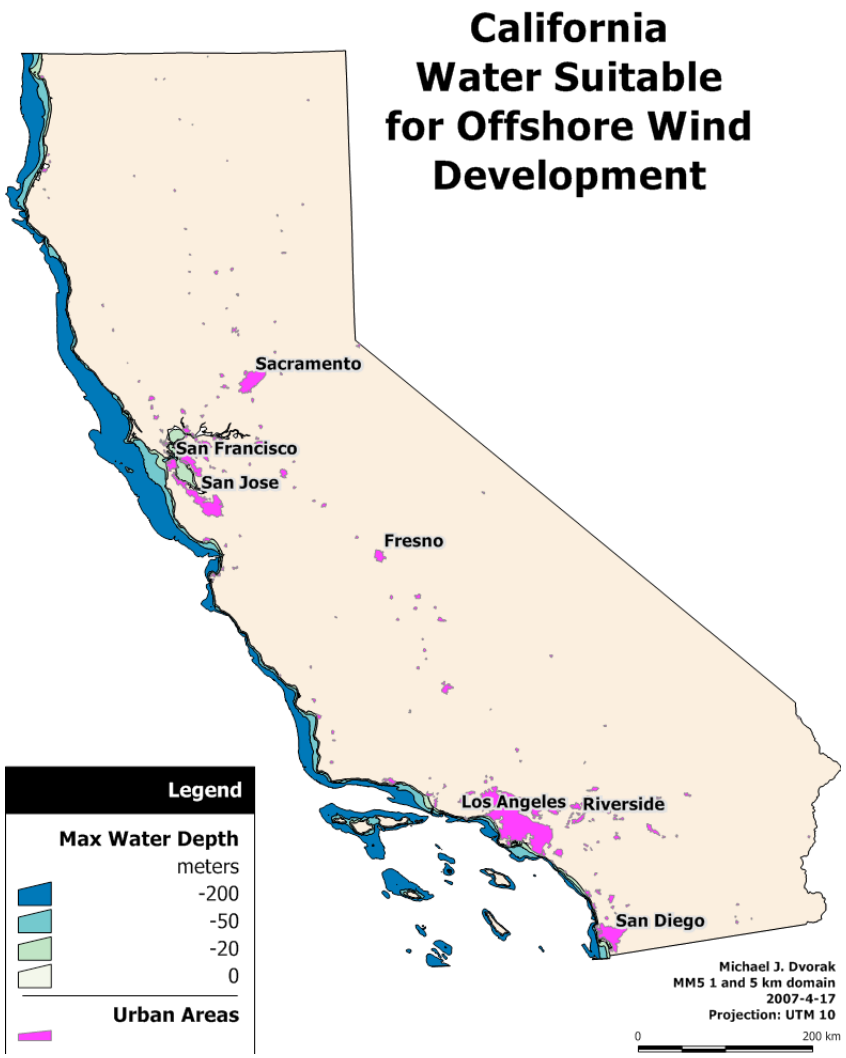
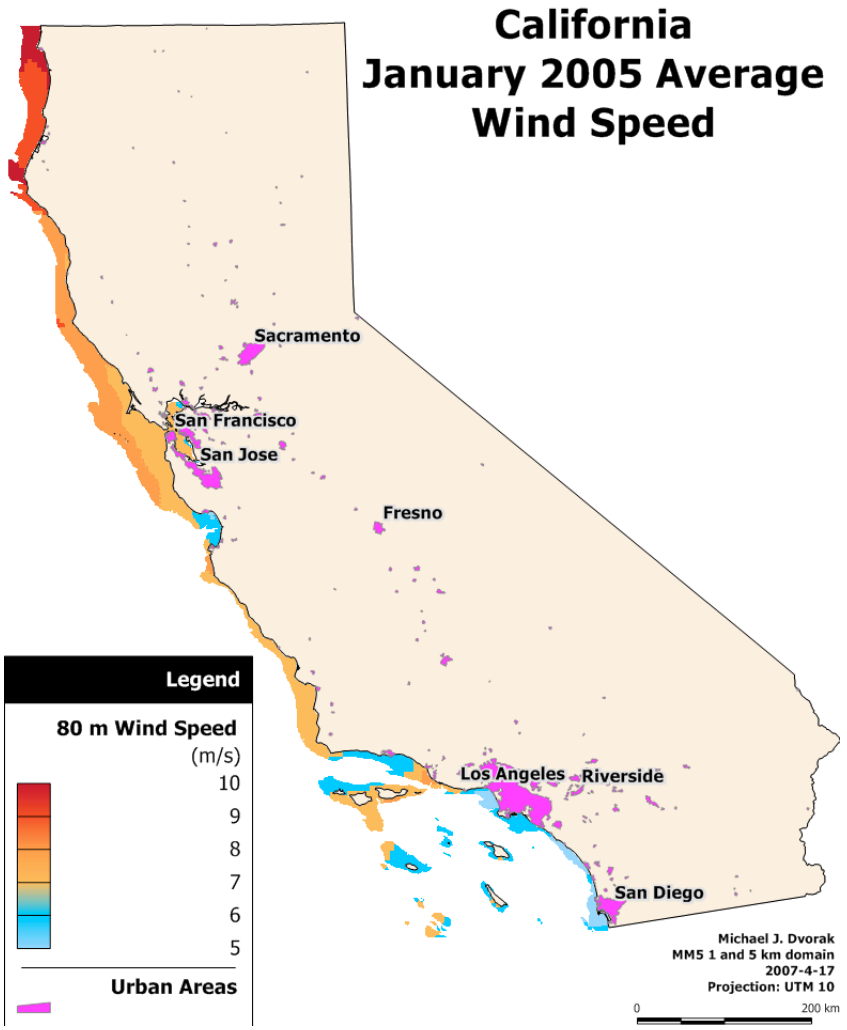
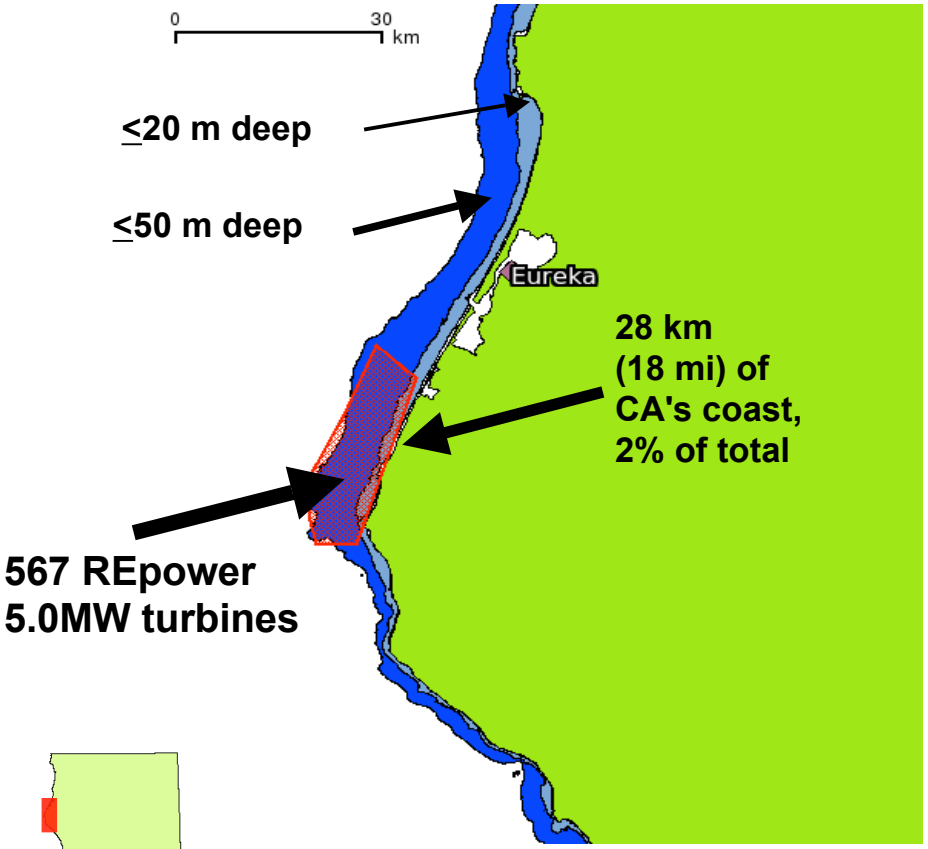
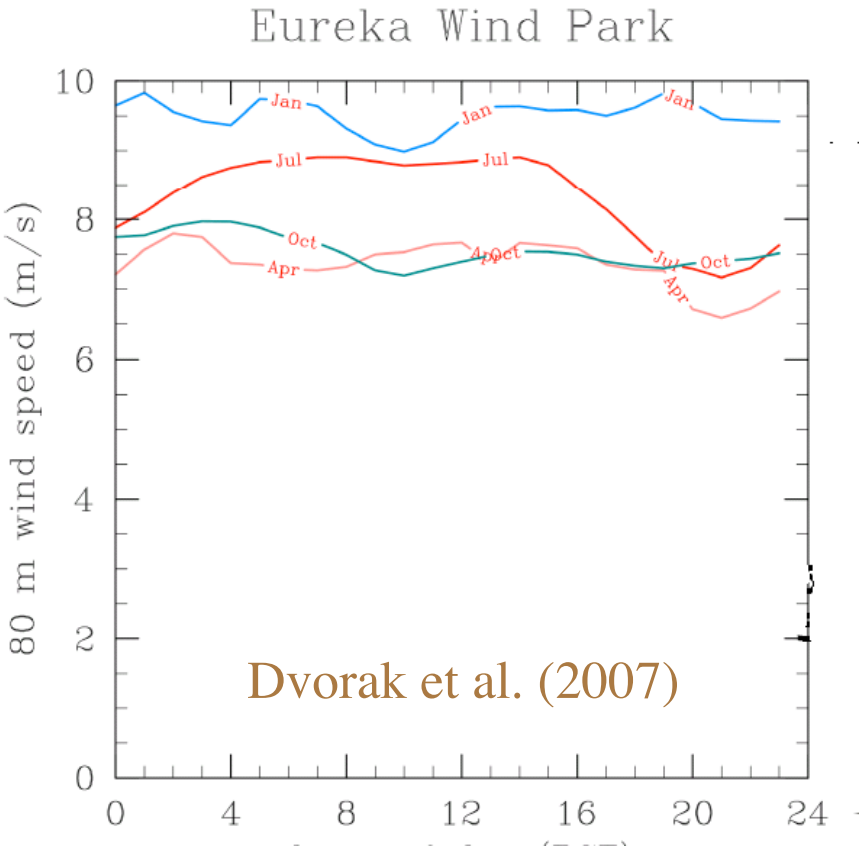


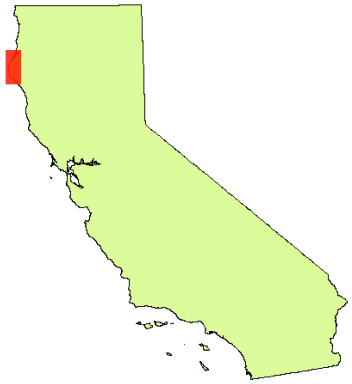


Dvorak et al. (2007)

Eureka Wind Park Example







Could produce 9.7 TWh annually, replacing 5.6% of CA's carbon-emitting electricity generation

- 2835 MW nameplate capacity
- 39% capacity factor (1 GW average power)

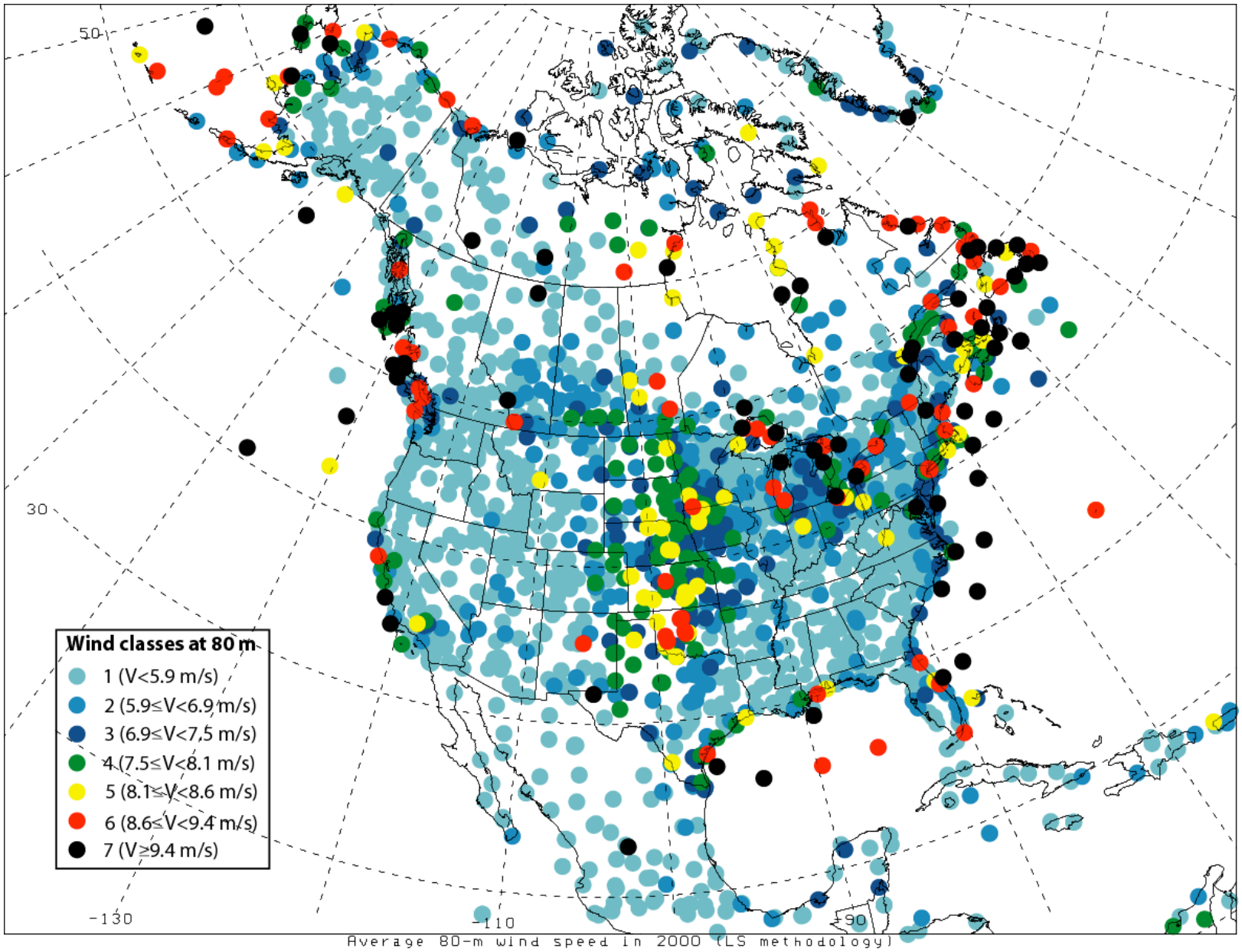
Global Wind Statistics

Global 80-m wind speed (m/s)	Land	Ocean
446 soundings+7753 surface stations*	4.54	8.60
All soundings (day)	4.96	
All soundings (night)	4.85	
Soundings+surface stations > 6.9 m/s	8.40	9.34
α= ln(V80/V10) / ln (80/10) from data	0.156	0.124
α from 1/7 power law	0.143	0.143

*80-m values over surface stations determined from least squares method. Archer and Jacobson (2005)

Mean 80-m Wind Speed in North America

Archer and Jacobson (2005) www.stanford.edu/group/efmh/winds/

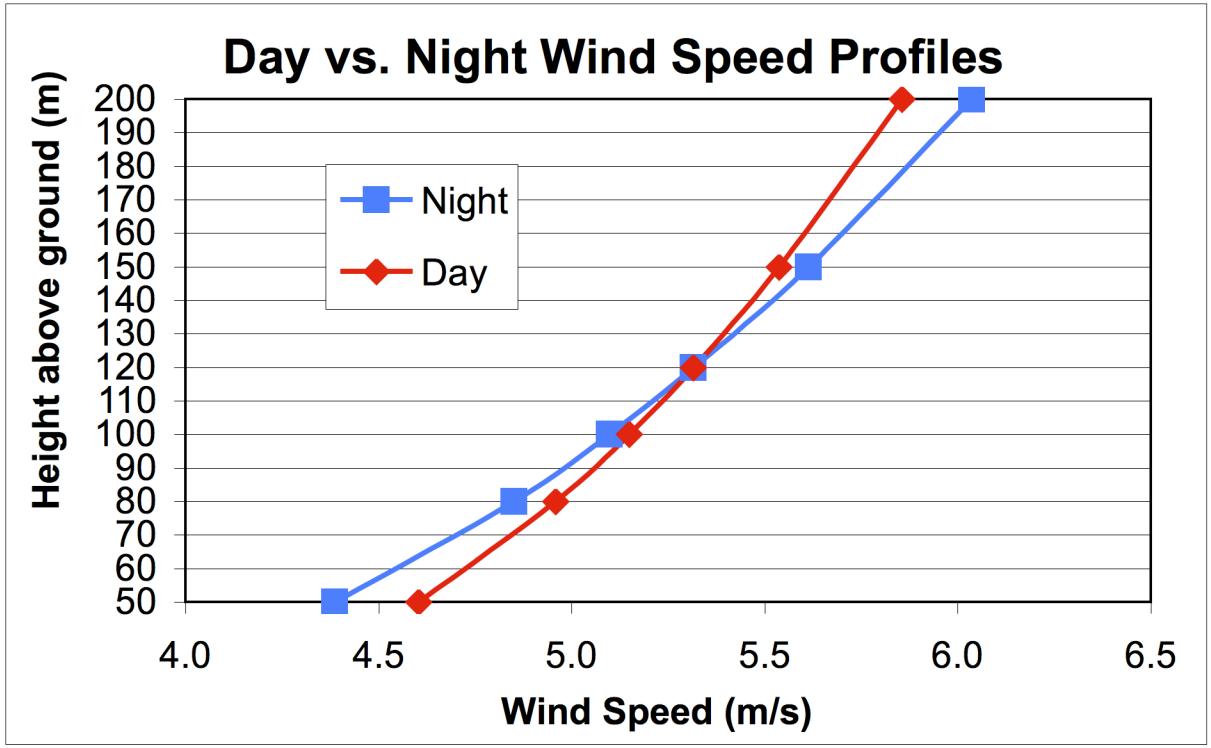


Percent of Land+Near Shore Stations With Annual Wind Speeds > 6.9 m/s at 80 m

Europe	14.2
North America	19.0
United States over land	15.0
United States over land+near shore	17.0
South America	9.7
Oceania	21.2
Africa	4.6
Asia	2.7
Antarctica	60
Global over land	13

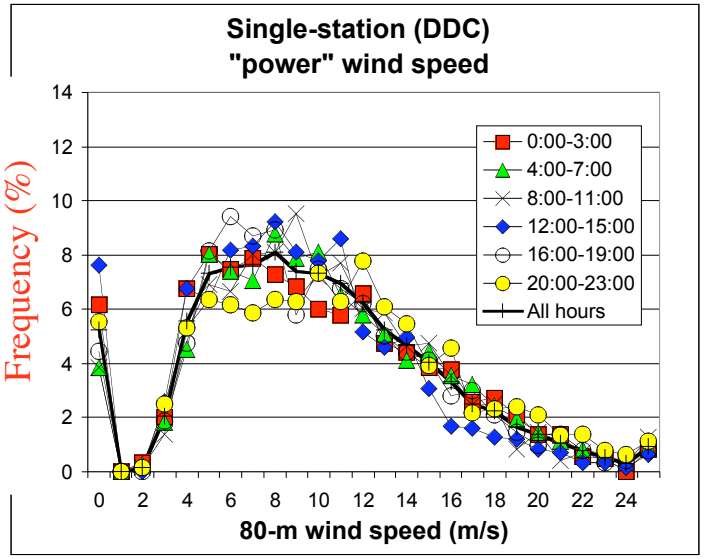
Archer and Jacobson (2005)

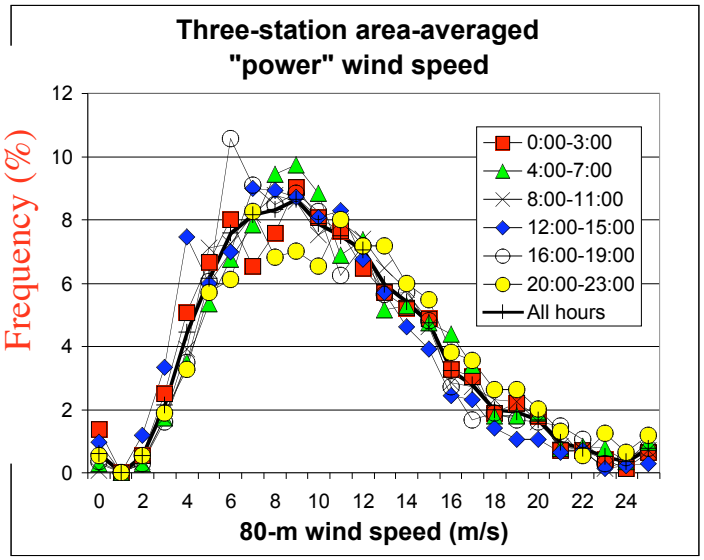
Global Day vs. Night Wind Speed Profiles Over Land From Soundings

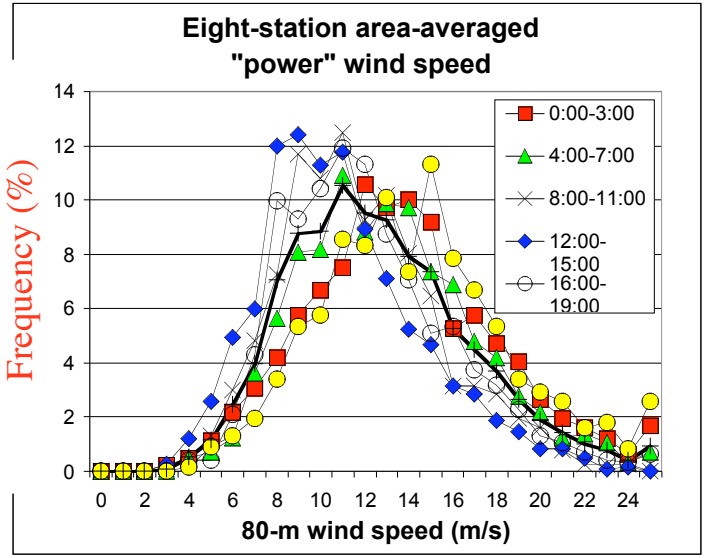


Archer and Jacobson (2005)

Wind Power v. Number of Farms



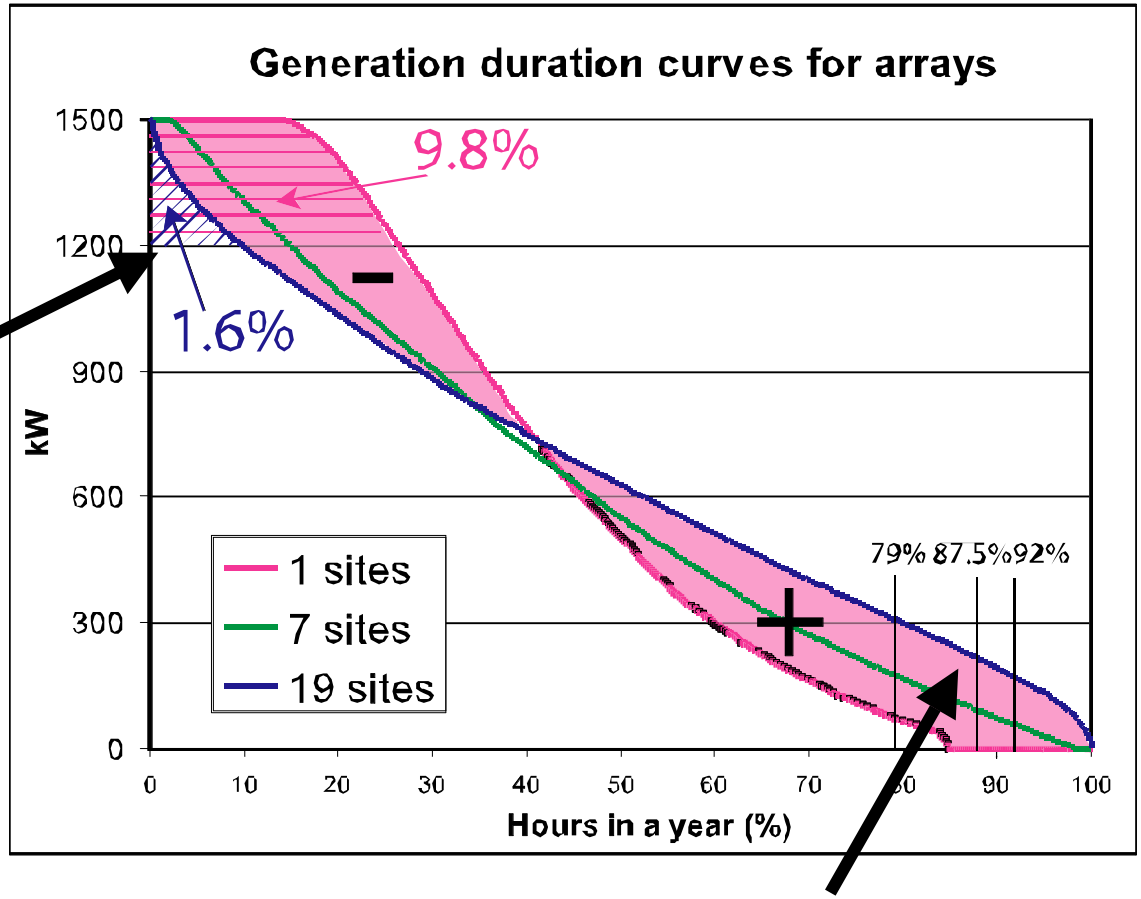




Archer and Jacobson (2003)

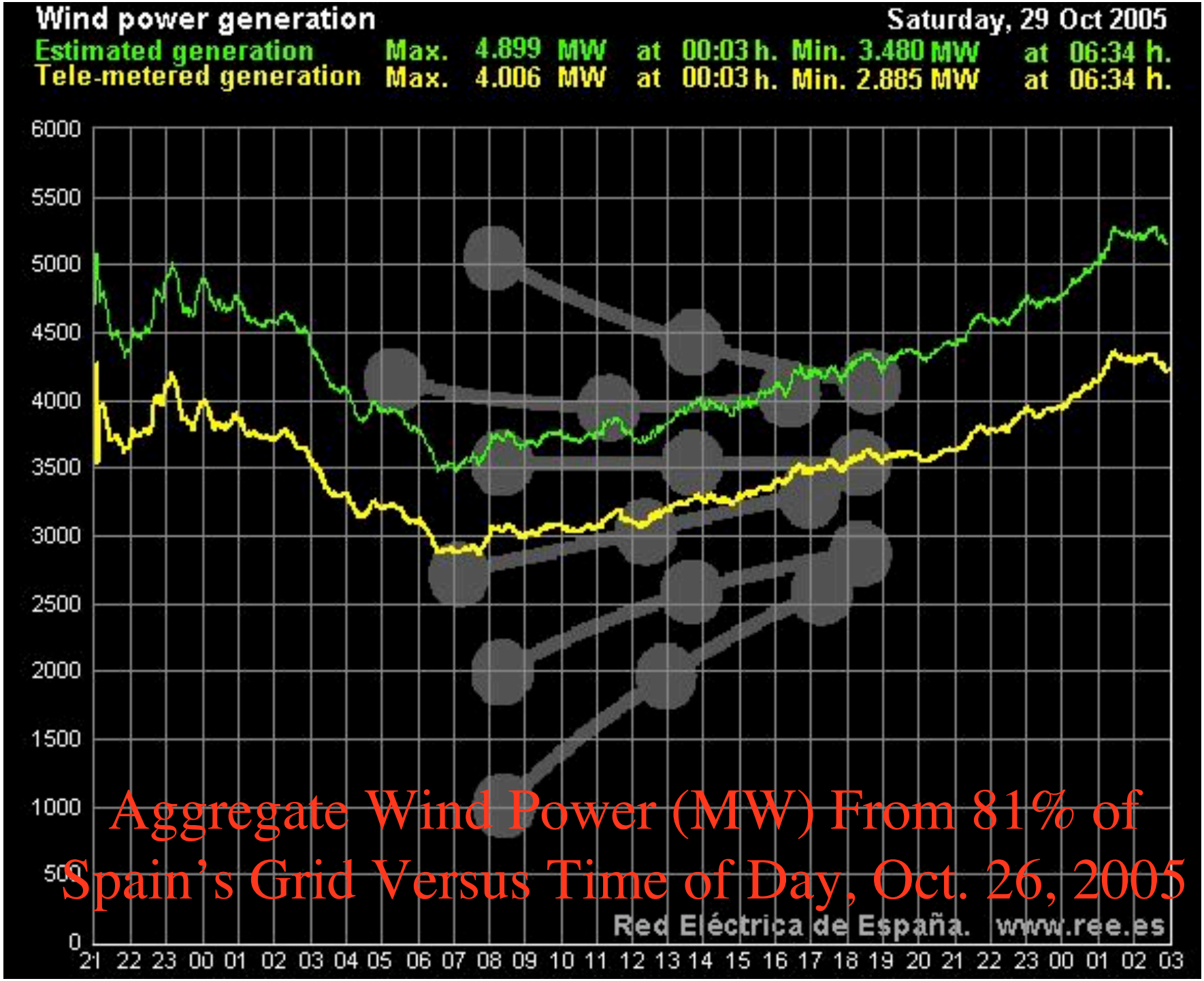
Firming Wind by Aggregating Farms

Reducing transmission capacity 20% reduces power 9.8% with 1 turbine but only 1.6% with 19 turbines



19 connected wind farms produce 33% firm power (222 kW out of 670 kW expected power from 1500 kW turbines) when operating at 87.5% reliability, the average for a U.S. coal plant).

Archer and Jacobson (2007)



Aggregate Wind Power (MW) From 81% of Spain's Grid Versus Time of Day, Oct. 26, 2005

Birds and Wind

U.S. bird deaths from current wind turbines 10,000-40,000/yr (!)
U.S. bird deaths from communication towers: 50 million/yr (!)
Worldwide bird deaths from avian flu: 200 million/yr (%)

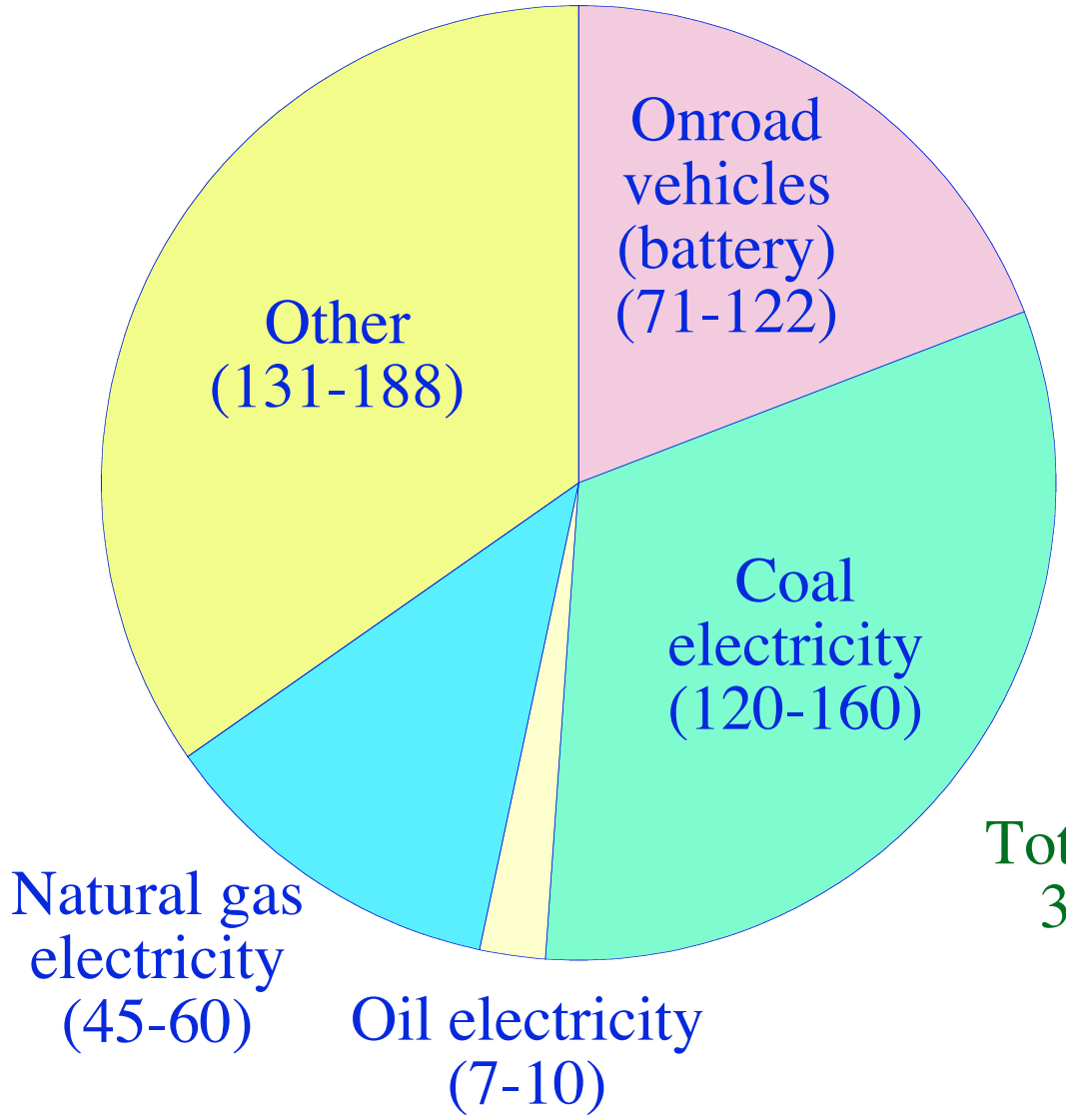
Est. bird deaths with 2,500,000 turbines worldwide: 2.5-10 million/yr

Outdoor human deaths reduced by these turbines: 800,000/yr (*)

The effect of wind turbines on birds will be small relative to the benefit of reducing fossil-biofuels on human and animal illness.

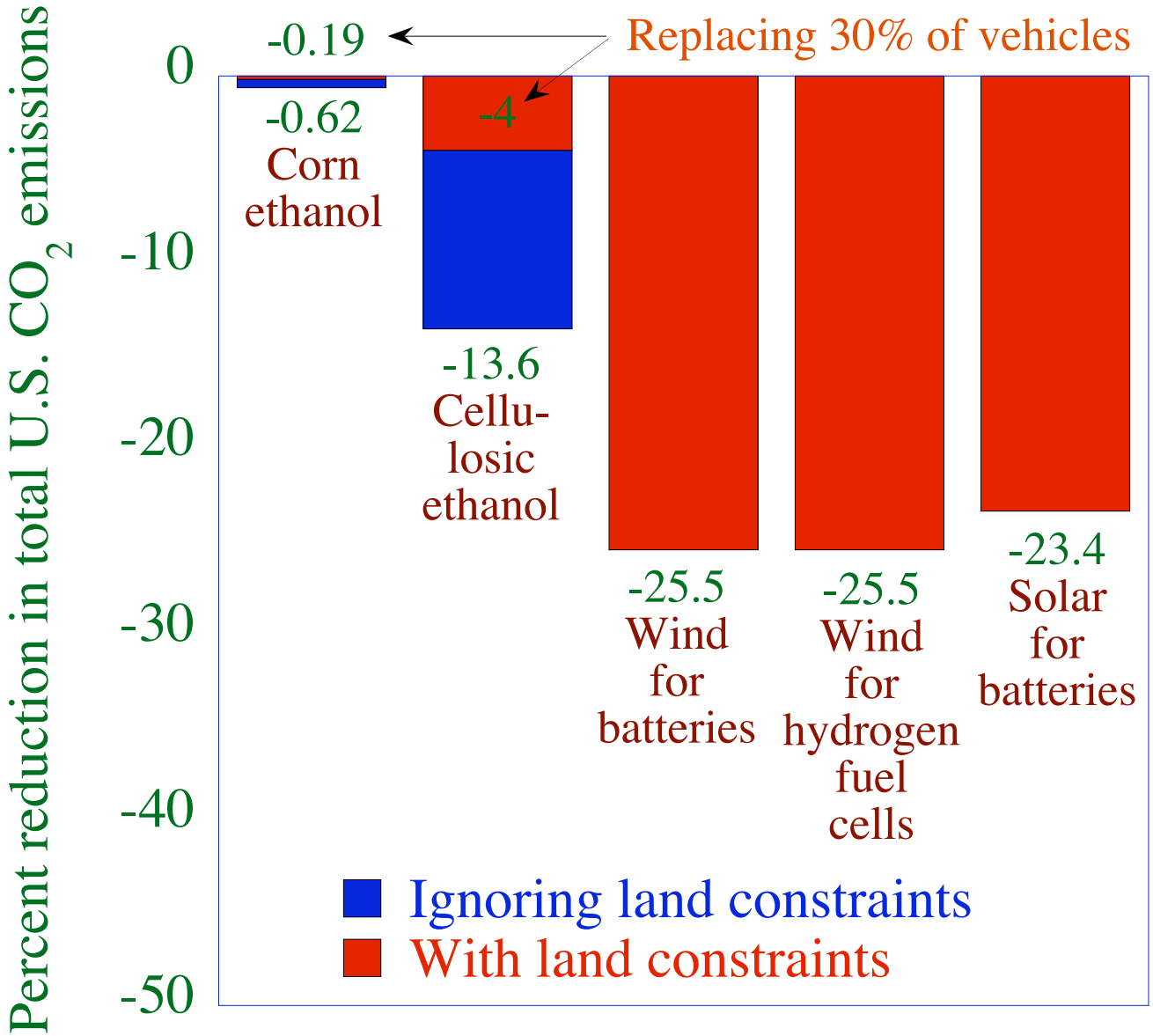
(!) Bird Conservancy (April 2006); (%) San Jose Mercury News (April 2006)
(*) World Health Organization (2002)

Thousands of 5 MW Wind Turbines Needed to Displace 100% U.S. CO_2

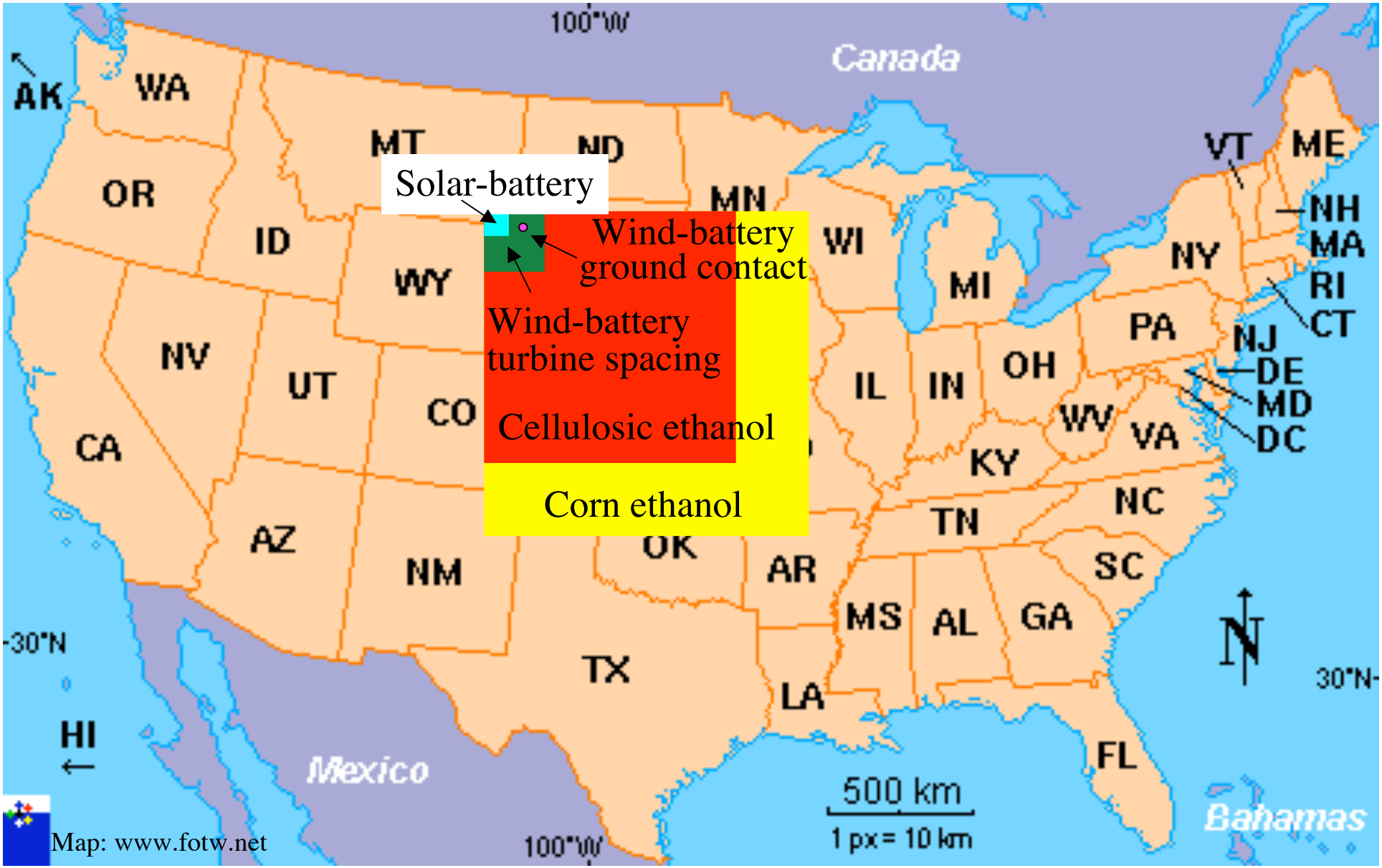


M.Z. Jacobson

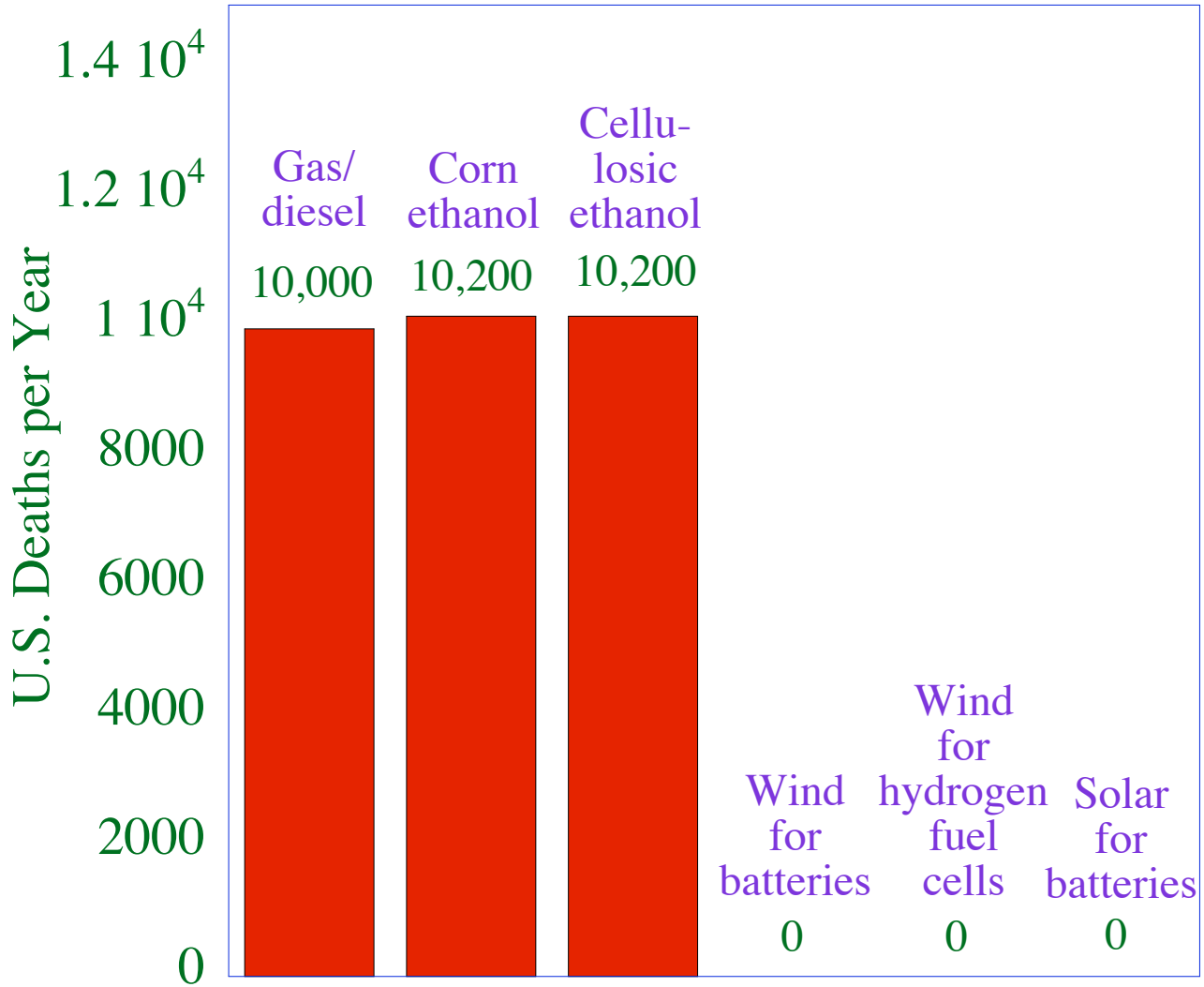
Percent Decrease in Total U.S. Carbon Dioxide Upon Replacing 100% of Onroad Vehicles



Area to Power 100% of U.S. Onroad Vehicles



Future U.S. Deaths Per Year From Onroad Vehicle Emissions



Summary

Wind, solar, hydro, and geothermal power can be combined for baseload or load-matching power supply, particularly in combination with plug-in electric vehicles.

California and the U.S. have significant wind resources. California's offshore resources were quantified. Interconnecting wind farms can convert about 1/3 of intermittent power to power with the same reliability as a coal-fired power plant.

Wind-battery electric vehicles could reduce U.S. CO_2 by 25.5%; solar-battery electric vehicles can reduce it by 23.4%. Corn-ethanol vehicles cannot practically reduce CO_2 in the U.S. by more than 0.07-0.2%.

Battery electric and hydrogen-fuel cell vehicles powered by renewable sources will eliminate 10,000-20,000 U.S. air pollution deaths each year. Ethanol vehicles will increase the death rate or cause no change. Wind turbines require 30 times less land than corn ethanol and 20 times less land than cellulosic ethanol for the same power.